Possible experiments to search for the neutron-mirror neutron oscillations

Yuri Pokotilovski

Joint Institute for Nuclear Research
Dubna, Russia

PHYSICAL REVIEW VOLUME 104, NUMBER 1 OCTOBER 1, 1956

Question of Parity Conservation in Weak Interactions*

T. D. LEE, *Columbia University, New York, New York*

AND

C. N. YANG,† *Brookhaven National Laboratory, Upton, New York*

(Received June 22, 1956)

The question of parity conservation in β decays and in hyperon and meson decays is examined. Possible experiments are suggested which might test parity conservation in these interactions.

RECENT experimental data indicate closely identical masses[1] and lifetimes[2] of the $\theta^+(\equiv K_{\pi 2}^+)$ and the $\tau^+(\equiv K_{\pi 3}^+)$ mesons. On the other hand, analyses[3] of the decay products of τ^+ strongly suggest on the grounds of angular momentum and parity conservation that the τ^+ and θ^+ are not the same particle. This poses a rather puzzling situation that has been extensively discussed.[4]

One way out of the difficulty is to assume that parity is not strictly conserved, so that θ^+ and τ^+ are two different decay modes of the same particle, which necessarily has a single mass value and a single lifetime. We wish to analyze this possibility in the present paper against the background of the existing experimental

PRESENT EXPERIMENTAL LIMIT ON PARITY NONCONSERVATION

If parity is not strictly conserved, all atomic and nuclear states become mixtures consisting mainly of the state they are usually assigned, together with small percentages of states possessing the opposite parity. The fractional weight of the latter will be called $\mathfrak{F}^2$. It is a quantity that characterizes the degree of violation of parity conservation.

The existence of parity selection rules which work well in atomic and nuclear physics is a clear indication that the degree of mixing, $\mathfrak{F}^2$, cannot be large. From such considerations one can impose the limit $\mathfrak{F}^2 \lesssim (r/\lambda)^2$, which for atomic spectroscopy is, in most cases, $\sim 10^{-6}$.

The conservation of parity is usually accepted without questions concerning its possible limit of validity being asked. There is actually no *a priori* reason why its violation is undesirable. As is well known, its violation implies the existence of a right-left asymmetry. We have seen in the above some possible experimental tests of this asymmetry. These experiments test whether the present elementary particles exhibit asymmetrical behavior with respect to the right and the left. If such asymmetry is indeed found, the question could still be raised whether there could not exist corresponding elementary particles exhibiting opposite asymmetry such that in the broader sense there will still be over-all right-left symmetry. If this is the case, it should be pointed out, there must exist two kinds of protons p_R and p_L, the right-handed one and the left-handed one. Furthermore, at the present time the protons in the laboratory must be predominantly of one kind in order to produce the supposedly observed asymmetry, and also to give rise to the observed Fermi-Dirac statistical character of the proton. This means that the free oscillation period between them must be longer than the age of the universe. They could therefore both be regarded as stable particles. Furthermore, the numbers of p_R and p_L must be separately conserved. However, the interaction between them is not necessarily weak. For

invariance is preserved in β decay. This however, will not be assumed in the following.

Calculation with this interaction proceeds exactly as usual. One obtains, e.g., for the energy and angle distribution of the electron in an allowed transition

$$N(W,\theta)dW\,\sin\theta d\theta=\frac{\xi}{4\pi^3}F(Z,W)pW(W_0-W)^2 \times\left(1+\frac{ap}{W}\cos\theta+\frac{b}{W}\right)dW\,\sin\theta d\theta, \quad (\text{A.2})$$

where

$$\xi=(|C_S|^2+|C_V|^2+|C_S'|^2+|C_V'|^2)|M_{\text{F.}}|^2 +(|C_T|^2+|C_A|^2+|C_T'|^2+|C_A'|^2)|M_{\text{G.T.}}|^2, \quad (\text{A.3})$$

$$a\xi=\tfrac{1}{3}(|C_T|^2-|C_A|^2+|C_T'|^2-|C_A'|^2)|M_{\text{G.T.}}|^2 -(|C_S|^2-|C_V|^2+|C_S'|^2-|C_V'|^2)|M_{\text{F.}}|^2, \quad (\text{A.4})$$

$$b\xi=\gamma[(C_S^*C_V+C_SC_V^*)+(C_S'^*C_V'+C_S'C_V'^*)]|M_{\text{F.}}|^2 +\gamma[(C_T^*C_A+C_A^*C_T)+(C_T'^*C_A'+C_A'^*C_T')] \times|M_{\text{G.T.}}|^2. \quad (\text{A.5})$$

In the above expression all unexplained notations are identical with the standard notations. (See, e.g., the article by Rose.[13])

The above expression does not contain any interference terms between the parity conserving part of

REVIEWS OF
MODERN PHYSICS

VOLUME 29, NUMBER 3 JULY, 1957

Relativistic Invariance and Quantum Phenomena*

EUGENE P. WIGNER

Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

INTRODUCTION

THE principal theme of this discourse is the great difference between the relation of special relativity and quantum theory on the one hand, and general relativity and quantum theory on the other. Most of the conclusions which will be reported on in connection with the general theory have been arrived at in collaboration with Dr. H. Salecker,[1] who has spent a year in Princeton to investigate this question.

The difference between the two relations is, briefly, that while there are no conceptual problems to separate the theory of special relativity from quantum theory, there is hardly any common ground between the general theory of relativity and quantum mechanics. The

is perhaps irritating. It does not alter the fact that the question of the consistency of the two theories can at least be formulated, that the question of the special relativistic invariance of quantum mechanics by now has more nearly the aspect of a puzzle than that of a problem.

This is not so with the general theory of relativity. The basic premise of this theory is that coordinates are only auxiliary quantities which can be given arbitrary values for every event. Hence, the measurement of position, that is, of the space coordinates, is certainly not a significant measurement if the postulates of the general theory are adopted: the coordinates can be given any value one wants. The same holds for

О ЗАКОНАХ СОХРАНЕНИЯ ПРИ СЛАБЫХ ВЗАИМОДЕЙСТВИЯХ

Л. Д. Ландау

Как известно, свойства K-мезонов создали в современной теоретической физике рудное положение. Корреляции между мезонами при τ-распаде ($K^+ \to 2\pi^+ + \pi^-$) при-одят к необходимости приписать K^+-мезонам состояние 0^-. Такая система, однако, е может распасться на два π-мезона ($K^+ \to \pi^+ + \pi^0$). Этот результат ставит нас перед илеммой, либо считать, что имеется два различных K-мезона, либо что при распаде (-мезонов имеет место нарушение законов сохранения. В первом случае приходится бъяснить равенство масс (с точностью до 2 электронных масс) и близость времен жизни, связанных с θ- и τ-распадами. Равенство масс K-мезонов можно пытаться бъяснить наличием неизвестного нам свойства симметрии ядерных сил, переводящего -мезон в θ-мезон, как это было сделано Ли и Янгом [1]. При этом, однако, если читать, что распад с учетом нейтрино ($K^+ \to \mu^+ + \nu$, $K^+ \to \mu^+ + \nu + \pi^0$, $K^+ \to e^+ +$ $+ \nu + \pi^0$) происходит одинаково у частиц различной четности, надо ожидать отличие

L NUOVO CIMENTO   Vol. V, N. 1   1° Gennaio 1957

On Parity Conservation and Neutrino Mass.

ABDUS SALAM
St. John's College - Cambridge

(ricevuto il 15 Novembre 1956)

1. – YANG and LEE[1] have recently suggested that present experimental evidence does not exclude the possibility that parity is not conserved in β-decay. If future experiments confirm this, it may be possible to relate parity-violation in neutrino-decays to the vanishing of neutrino mass and self-mass. The argument as follows: the free neutrino Lagrangian is invariant for the substitution $\psi_\nu \to \gamma_5\psi_\nu$ $(\bar{\psi}_\nu \to -\bar{\psi}_\nu\gamma_5)$. If it is further postulated that neutrino interactio...

Vol

Re

TH ... ity and ... relativi ... the cor ... with th ... laborat ... year in ...

The ... that while there are no conceptual problems to separate the theory of special relativity from quantum theory, there is hardly any common ground between the general

... ment of position, that is, of the space coordinates, is certainly not a significant measurement if the postulates of the general theory are adopted: the coordinates can be given any value one wants. The same holds for

ЯДЕРНАЯ ФИЗИКА
JOURNAL OF NUCLEAR PHYSICS
т. 3, вып. 6, 1966

О ВОЗМОЖНОСТИ ЭКСПЕРИМЕНТАЛЬНОГО ОБНАРУЖЕНИЯ ЗЕРКАЛЬНЫХ ЧАСТИЦ

И. Ю. КОБЗАРЕВ, Л. Б. ОКУНЬ, И. Я. ПОМЕРАНЧУК

ИНСТИТУТ ТЕОРЕТИЧЕСКОЙ И ЭКСПЕРИМЕНТАЛЬНОЙ ФИЗИКИ ГКИАЭ

(Поступила в редакцию 29 декабря 1965 г.)

В связи с обнаружением нарушения *CP*-инвариантности в распаде $K_2^0 \to 2\pi$, обсуждается возможность существования наряду с обычными частицами (L) «зеркальных» частиц (R), введение которых восстанавливает эквивалентность левого и правого. Показано, что «зеркальные» частицы не могут взаимодействовать с обычными частицами ни сильно, ни полусильно, ни электромагнитно. Допустимо слабое взаимодействие между L и R частицами, обусловленное обменом нейтрино. L и R частицы должны иметь общее гравитационное взаимодействие. Обсуждается вопрос о существовании макроскопических тел (звезд) из R вещества и возможность их обнаружения.

1. Зеркальные частицы и CPA-инвариантность

В настоящее время представляется почти несомненным, что в опытах [1-4] действительно наблюдается распад $K_2^0 \to 2\pi$ и *CP*-инвариантность нарушается. Это означает, что эквивалентность правого и левого отсутствует в мире наблюдаемых частиц.

CP-неинвариантность в отличие от неинвариантности относительно собственной группы Лоренца не приводит к реальным теоретическим осложнениям. Действительно, лагранжиан с комплексными константами дает *CP*-неинвариантную, но унитарную, аналитическую и *CPT*-инвариантную

Broken MP symmetry

Mirror particles from GUT

Mirror particles from superstrings

Thermodynamics and Baryogenesis in the Mirror world

Mirror world at the LHC

Mirror Dark matter

Mirror astronomic objects

Mirror matter in Solar system

MACHO gravitational microlensing

Orthopositronium

Existing experimental constraints

Possible experiments

$$G_{SM} \otimes G'_{SM}$$
$$G_{SM} = SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$$
$$G'_{SM} = \left[SU(3)_c \otimes SU(2)_L \otimes U(1)_Y\right]'$$

$$l_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \sim (1,2,-1); \qquad l_R = \begin{matrix} N_R \sim (1,1,0)? \\ e_R \sim (1,1,-2) \end{matrix}$$

$$q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \sim (3,2,1/3); \qquad q_R = \begin{matrix} u_R \sim (3,1,4/3) \\ d_R \sim (3,1,-2/3) \end{matrix}$$

$$\tilde{l}_R = \begin{pmatrix} \tilde{\nu}_R \\ \tilde{e}_R \end{pmatrix} \sim (1,2,1); \qquad \tilde{l}_L = \begin{matrix} \tilde{N}_L \sim (1,1,0)? \\ \tilde{e}_L \sim (1,1,2) \end{matrix}$$

$$\tilde{q}_R = \begin{pmatrix} \tilde{u}_R \\ \tilde{d}_R \end{pmatrix} \sim (3,2,-1/3); \qquad \tilde{q}_L = \begin{matrix} \tilde{u}_L \sim (3,1,-4/3) \\ \tilde{d}_L \sim (3,1,2/3) \end{matrix}$$

$$x \leftarrow -x; \qquad t \leftarrow t$$
$$W^\mu \rightarrow W'_\mu; \qquad B^\mu \rightarrow B'_\mu; \qquad G^\mu \rightarrow G'_\mu$$
$$l_L \leftrightarrow \gamma_0 l'_R; \qquad e_R \leftrightarrow \gamma_0 e'_L; \qquad q_L \leftrightarrow \gamma_0 q'_R$$
$$u_R \leftrightarrow \gamma_0 u'_L; \qquad d_R \leftrightarrow \gamma_0 d'_L$$

$$L = \frac{\epsilon}{2} F^{\mu\nu} F'_{\mu\nu}$$

$$n \longrightarrow \tilde{n}$$

$$\frac{1}{M^5}(udd)(udd) + \frac{1}{M^5}(qqd)(qqd) + h.c.$$

$$n \longrightarrow n'$$

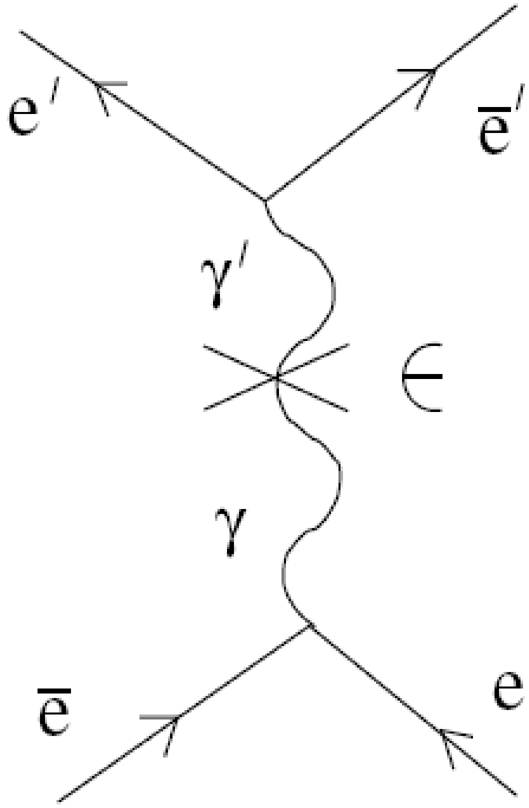
$$\frac{1}{M^5}(udd)(u'd'd') + \frac{1}{M^5}(qqd)(q'q'd') + h.c.$$

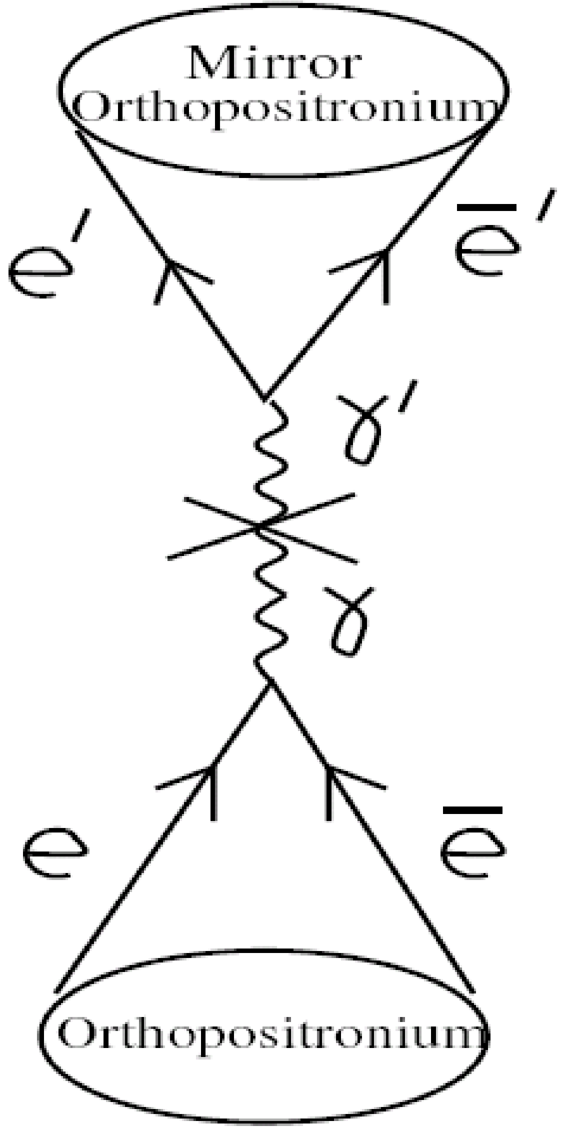
$$\Delta\ \mathrm{B}=1, \qquad \Delta\ \mathrm{B}'=1$$

$$\Lambda^6_{QCD} \sim 10^{-4} GeV^6$$

$$\delta m \sim \left(\frac{10TeV}{M}\right)^5 \times 10^{-15} eV$$

$$L = \frac{\epsilon}{2} F^{\mu\nu} F'_{\mu\nu}$$





Mirror
Orthopositronium
e'
$\bar{e}'$
γ'
γ
e
$\bar{e}$
Orthopositronium

$$E_{thresh} \approx \frac{m_p m_\pi}{2E_\gamma} = 6 \times 10^{19} eV$$

$$\mathrm{p} + \gamma \longrightarrow \mathrm{n} + \pi^{+}$$

$$\Downarrow$$

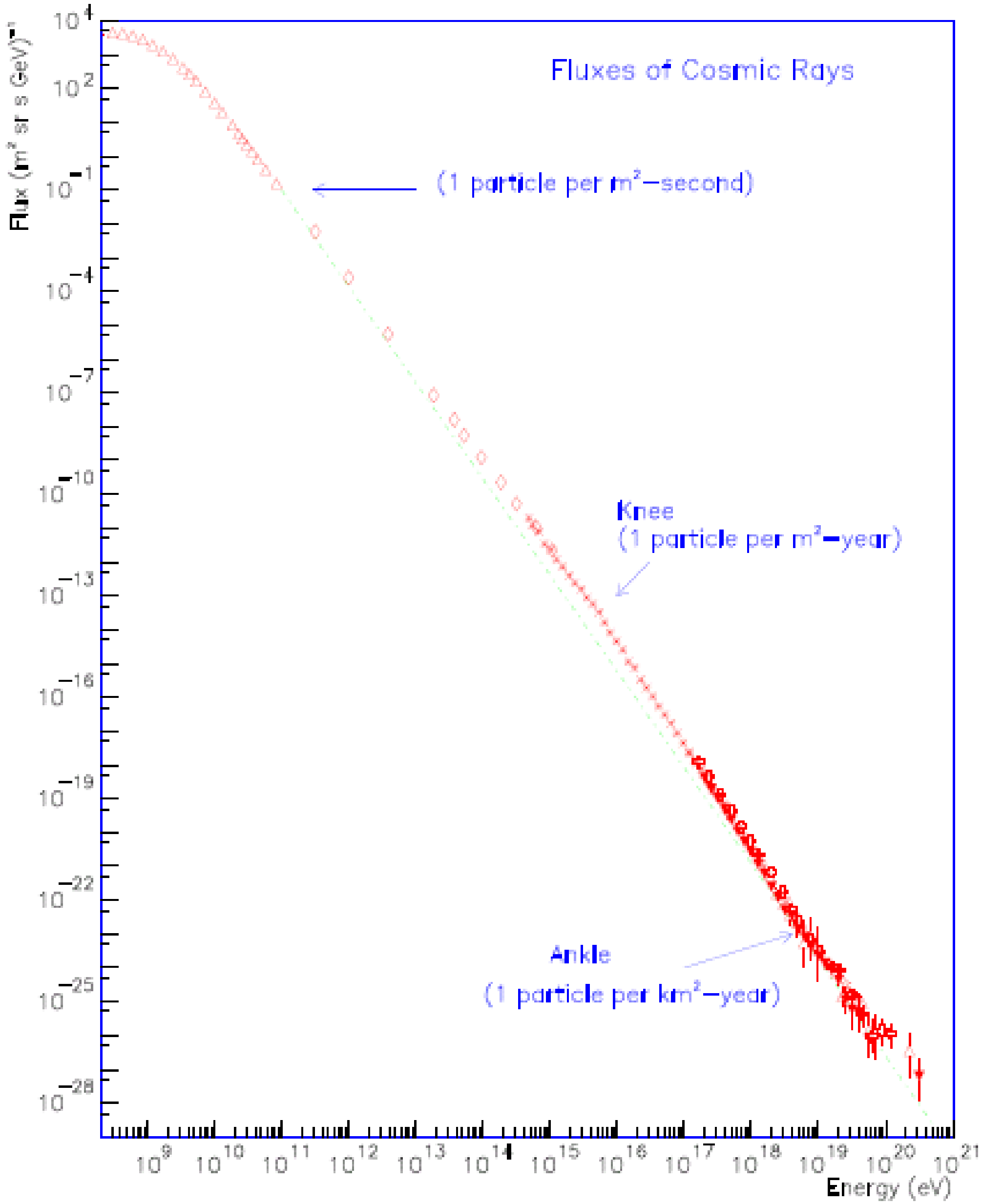
$$\mathrm{n}' \longrightarrow \mathrm{p}' + \mathrm{e}' + \tilde{\nu}'$$

$$\downarrow$$

$$\mathrm{p}' + \gamma' \longrightarrow \mathrm{n}' + \pi'^{+}$$

$$\Downarrow$$

$$\mathrm{n} \longrightarrow \mathrm{p} + \mathrm{e} + \tilde{\nu}$$


Fluxes of Cosmic Rays
(1 particle per m²−second)
Knee
(1 particle per m²−year)
Ankle
(1 particle per km²−year)
Flux (m² sr s GeV)⁻¹
Energy (eV)

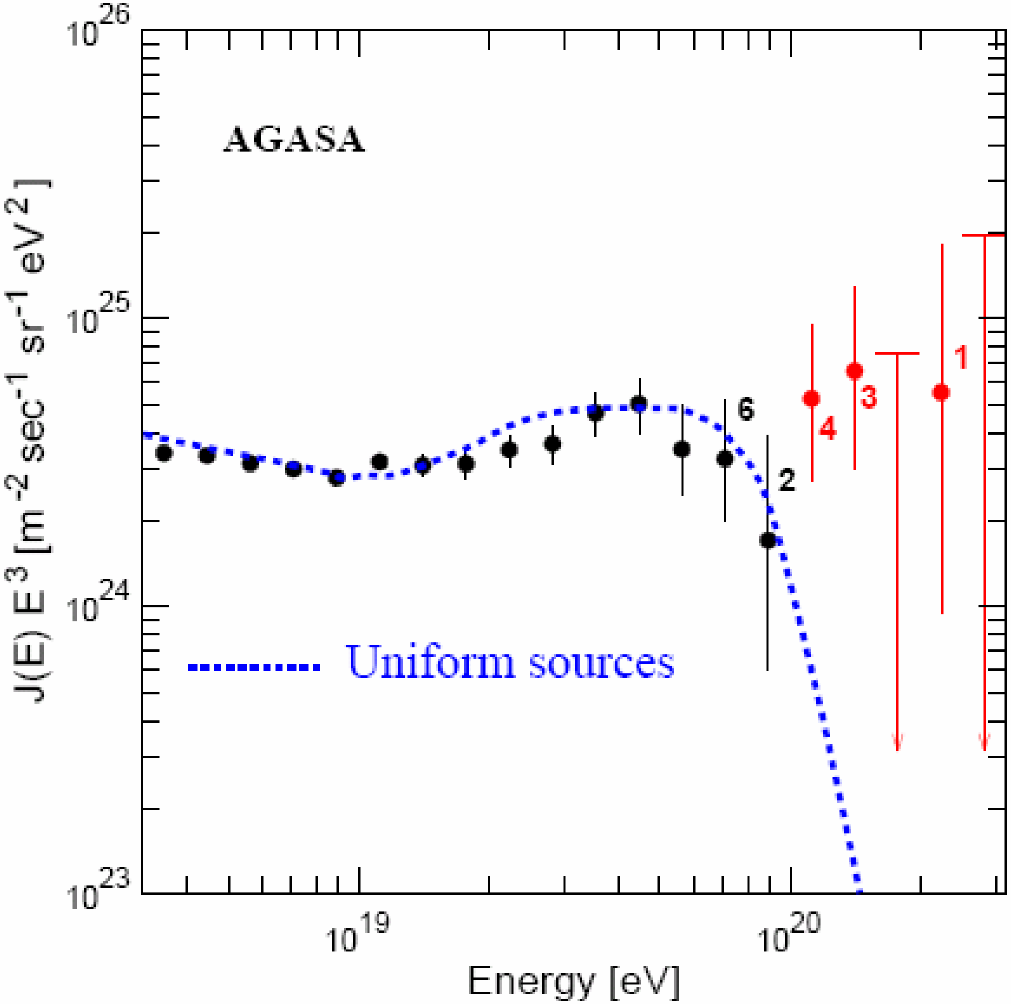


FIGURE 2. Highest energy region of the cosmic ray spectrum as observed by the AGASA detector. The figures near the data points indicate the number of events in the corresponding energy bin. The arrows show 90% confidence level upper limits. The dashed line is the expected spectrum if the sources were cosmologically distributed.

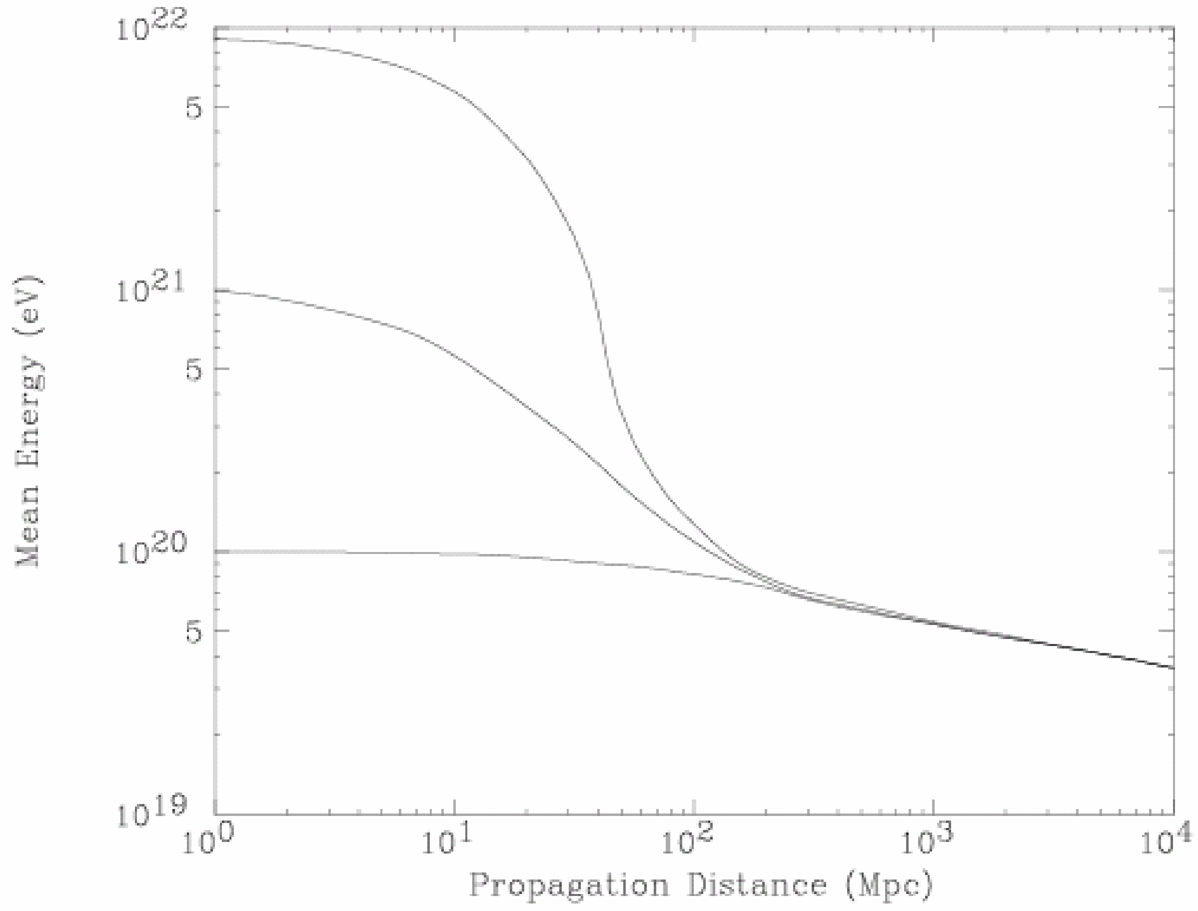
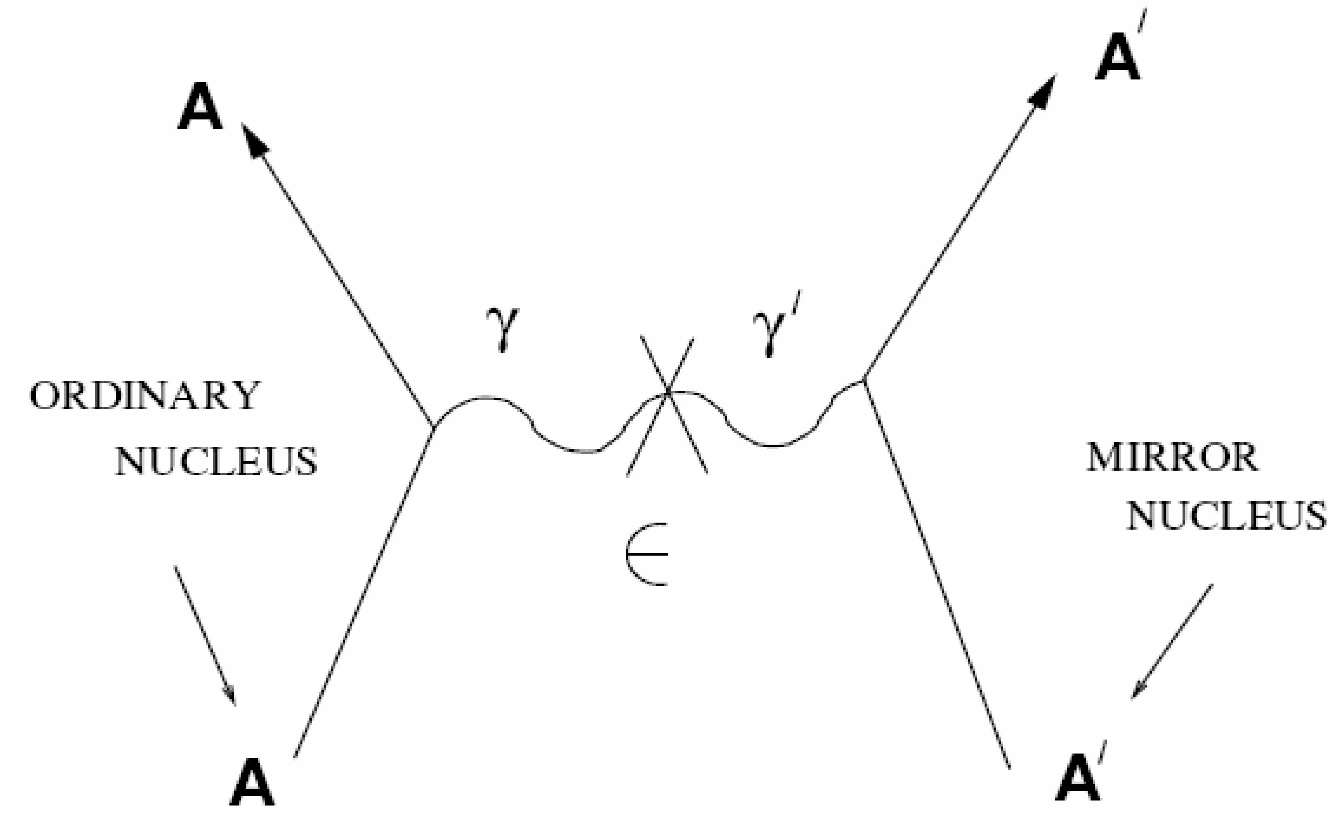


Figure 4: Mean energy of protons as a function of propagation distance through the CMB. Curves are for energy at the source of 10^{22} eV, 10^{21} eV, and 10^{20} eV.


A
A'
γ
γ'
ORDINARY
NUCLEUS
MIRROR
NUCLEUS
∈
A
A'

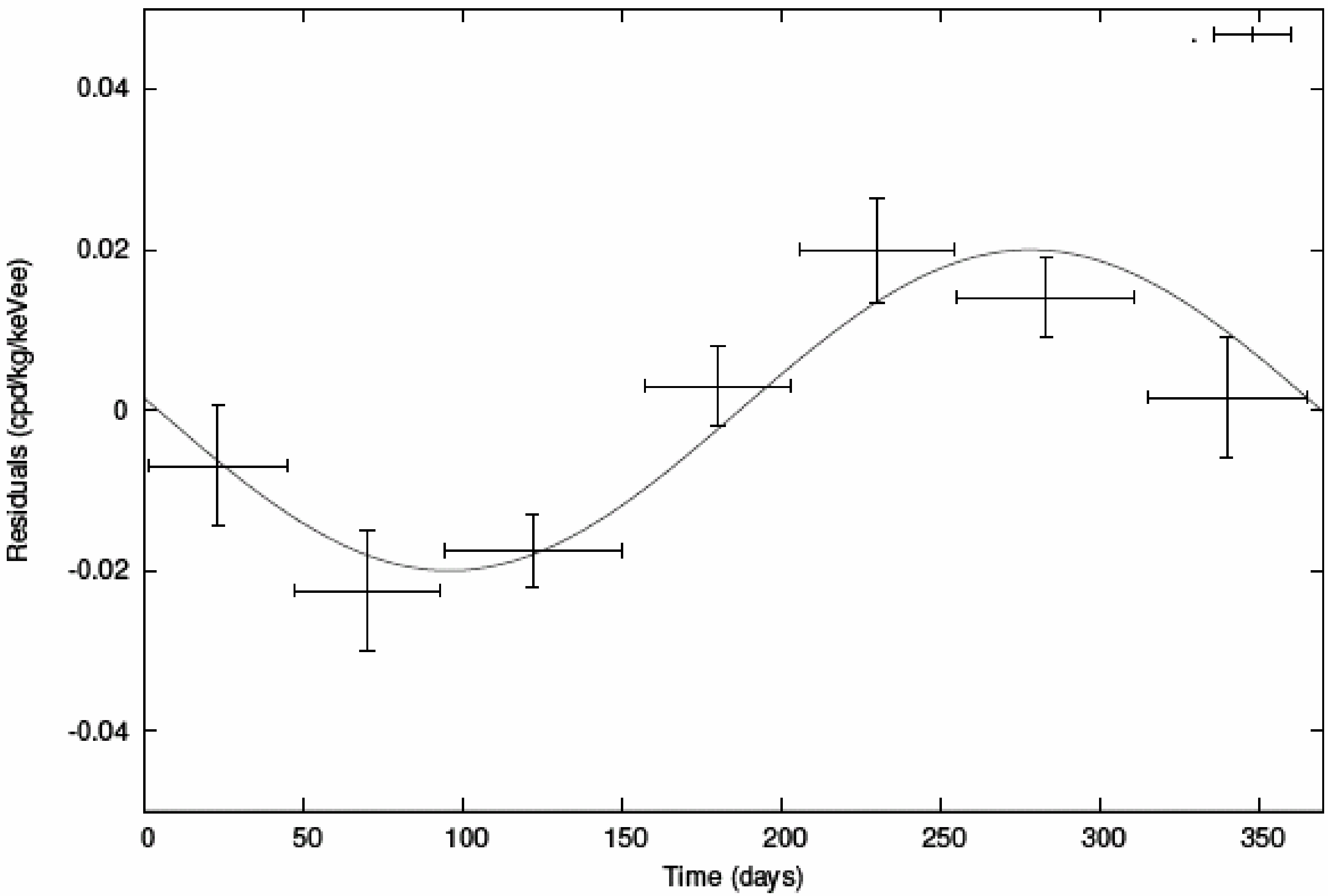


Fig. 3. DAMA/NaI annual modulation signal (taking data from the second paper of Ref. 35) together with the mirror matter prediction (initial time is August 7th).

DAMA/NAI experiment

Count rate = A $\cos\left[2\pi\frac{t-t_0}{T}\right]$

T=(1±0.01) year

t_0=(144±22) days

t_0^{expect}=152 (2 June)

when v_{earth} reaches its maximum

A=(0.020±0.003)day^{-1}kg−1keV−1

$$L = \bar{\psi} M \psi, \tag{1}$$

$$\psi = \begin{pmatrix} n \\ n' \end{pmatrix} \tag{2}$$

$$M = \begin{pmatrix} M & \delta m \\ \delta m & M' \end{pmatrix} \tag{3}$$

$$n'(t) = n(0)\frac{\delta m^2}{\delta m^2 + \Delta E^2} sin^2(\sqrt{\Delta E^2 + \delta m^2} \cdot t). \tag{4}$$

$$M - M' = 2\Delta E = \mu B, \qquad \mu = 6 \cdot 10^{-12}\ \mathrm{eV/G},$$
$$\tau_{osc} = \hbar/\delta m, \qquad \omega = \Delta E/\hbar$$

$$n'(t) = \frac{n(0)}{1 + (\omega\tau_{osc})^2} sin^2(\sqrt{1 + (\omega\tau_{osc})^2} \cdot t/\tau_{osc}), \tag{5}$$

$\omega \approx 4.8 \times 10^3\ \mathrm{s}^{-1}$ in the field $B = 1$ G, $\qquad \omega\tau_{osc} \gg 1,$

$$\omega t \gg 1, \qquad n'(t) = \frac{n_0}{2(\omega\tau_{osc})^2}. \tag{6}$$

$$\omega t \ll 1, \qquad n'(t) = n_0(t/\tau_{osc})^2. \tag{7}$$

Beam experiment

$$\phi_{n'}(t) = \phi_0 (L/v\tau_{osc})^2.$$

$$\phi_0 (\frac{L}{v\tau_{osc}})^2 T_{exp} < (2\phi_0 T_{exp})^{1/2}, \qquad (8)$$

$$\tau_{osc} > \frac{L}{v}(\phi_0 T_{exp}/2)^{1/4}. \qquad (9)$$

$\phi_0 \approx 3 \times 10^7\ \mathrm{s}^{-1}$, $\quad v \approx 100$ m/s, $\quad L = 5$ m,

$T_{exp} = 1$ month $\approx 2.5 \cdot 10^6$ s, $\quad \tau_{osc} > 125$ s.

Process $n \to n' \to n$

$$w = (L/2v\tau_{osc})^2,$$

$$\phi_n(t) = \phi_0(\frac{L}{2v\tau_{osc}})^4, \tag{10}$$

$$\phi_0(\frac{L}{2v\tau_{osc}})^4 T_{exp} < (2\phi_{bgr}T_{exp})^{1/2}, \tag{11}$$

$$\tau_{osc} > \frac{L}{2v}(\phi_0)^{1/4}(\frac{T_{exp}}{2\phi_{bgr}})^{1/8}. \tag{12}$$

$$\phi_{bgr} = 0.01 \text{ s}^{-1}, \qquad \tau_{osc} > 20 \text{ s}.$$

The storage of ultracold neutrons.

$$f \approx < v/d >, \quad 1)\ \lambda \approx f/2(\omega_B \tau_{osc})^2 \quad 2)\ \lambda \approx 1/f\tau_{osc}^2$$

$$(\omega_B = \omega \cdot B(G)),$$

$$\alpha \sim 10^{-6}\ \mathrm{s}^{-1},\ \tau_{osc} > 1/(f\alpha)^{1/2},$$

$$f \sim (5-10)s^{-1},\ \tau_{osc} > 300 - 500\ \mathrm{s}.$$

!

$$(5.47 \pm 2.85) \cdot 10^{-6}\ \mathrm{s}^{-1}, \qquad (9.7 \pm 2.8) \cdot 10^{-6}\ \mathrm{s}^{-1}.$$

$$n \to H + \tilde{\nu}_e, \qquad \lambda_H \sim 4 \cdot 10^{-9}\ \mathrm{s}^{-1},$$

$$\lambda = f/2(\omega_B \tau_{osc})^2, \qquad \tau_{osc} = (f/2\lambda)^{1/2}/\omega_B.$$

$$\omega_B \sim 2.4 \cdot 10^3\ \mathrm{s}^{-1}, \qquad \lambda = 5 \cdot 10^{-6}\ \mathrm{s}^{-1}, \qquad \tau_{osc} = 0.3 - 0.4\ \mathrm{s}$$

The results of the neutron lifetime measurements in the beam experiments and in the UCN storage experiments. Only the results with uncertainties not exceeding 10 s were taken into consideration.

Beam experiments	**Storage experiments**
891±9 (1988, Spivak)	877±10 (1989, Paul)
893.6±3.8±3.7 (1990, Byrne 1)	870±8 (1989, Kharitonov)
889.2±3.0±3.8 (1996, Byrne 2)	887.6±3.0 (1989, Mampe)
886.8±1.2±3.2 (2003, Dewey)	888.4±3.3 (1992, Nesvizhevsky)
	882.6±2.7 (1993, Morozov)
	885.4±0.9±0.4 (2000, Arzumanov)
	881.±3.0 (2000, Pichlmaier)
	878.5±0.7±0.3 (2004, Serebrov)
Averaged value	**Average value without (Serebr)**
889.2±2.4	884.9±0.8
	Average value including (Serebr)
	881.6±0.6

UCN flow experiment.

$$\frac{dN}{dt} = \phi_0 s_{in} - \rho \frac{Sv}{4}\mu - \rho \frac{(s_{in} + s_{out})v}{4} - \frac{N}{\tau_n} = 0. \qquad (13)$$

$$\rho = \frac{4\phi_0 s_{in}}{v(S\mu + s_{in} + s_{out} + \delta)}, \qquad (14)$$

$\delta = 4V/v\tau_n$.

$$\frac{d\rho}{d\mu} = -\frac{4\phi_0 S s_{in}}{v(S\mu + s_{in} + s_{out} + \delta)^2}. \qquad (15)$$

$$I_{det} = \rho s_{out} v/4 = \frac{\phi_0 s_{in} s_{out}}{S\mu + s_{in} + s_{out} + \delta}. \qquad (16)$$

$$\Delta I = -\frac{\phi_0 S s_{in} s_{out} \Delta\mu}{(S\mu + s_{in} + s_{out} + \delta)^2}. \qquad (17)$$

$$\frac{1}{(f\tau_{osc})^2}\frac{\phi_0 S s_{in} s_{out} T_{exp}}{(S\mu + s_{in} + s_{out} + \delta)^2} < \Big(\frac{2\phi_0 S s_{in} s_{out} T_{exp}}{S\mu + s_{in} + s_{out} + \delta}\Big)^{1/2}. \qquad (18)$$

$$\tau_{osc} > \frac{1}{2^{1/4} f}\frac{(T_{exp}\phi_0 s_{in} s_{out})^{1/4} S^{1/2}}{(S\mu + s_{in} + s_{out} + \delta)^{3/4}}. \qquad (19)$$

$\mu \sim 10^{-5}$, $\quad S\mu \ll s_{in}, s_{out}$, $\quad f \approx < v/d >$

$< d > \sim 4V/S$, $\quad s_{in} = s_{out} = s \gg 4V/(\tau_n v)$,

$$\tau_{osc} \approx 0.13\Big(\frac{T_{exp}\phi_0}{s}\Big)^{1/4}\frac{l^2}{v}. \qquad (20)$$

$T_{exp} \approx 2.5 \cdot 10^6$ s, $\phi_0 = 10^3$ cm^{-2} s^{-1}, l=100 cm, s=10 cm^2, v=400 cm/s, $\tau_{osc} \approx 420$ s.

$U_0 \ll E$, $\quad B \sim 0.1$ G, $\quad , U_0 \approx 5 \times 10^{-4}$ neV,

$R = (\pi k_0 x_0)^2 (U_0/E) exp(-4\pi k x_0)$,

$k_0 = (2mU_0)^{1/2}/\hbar$, $E \sim 0.01$ neV, $x_0 \sim 10$ cm, $k \sim 10^4$ cm^{-1}.